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This report gives an account of the work conducted by NORSAR in conjunction with high frequency seismic signal propagation studies. A high Frequency Seismic Element (HFSE) was installed in the NORESS array. Data from the HFSE has been received and stored on magnetic tape. Analyses of the data are on-going. Initial results provide evidence that signal frequencies up to at least 50Hz can contribute significantly to enhancing seismic monitoring capabilities at regional distances.

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FINAL TECHNICAL REPORT

for project

HIGH FREQUENCY SEISMIC SIGNAL PROPAGATION STUDIES

Frode Ringdal

Principal Investigator

Kjeller, Norway, 28 November 1986

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I. SUMMARY

This final report gives an account of the work conducted by NORSAR in conjunction with high frequency seismic signal propagation studies during the period 30 September 1985 - 29 September 1986 under Contract No. F49620-85-C-0146.

The purpose of this research is to study methods to exploit the extremely good propagation of high-frequency energy for regional seismic phases in Eurasia. Since Scandinavia is located within the same geologic plate boundary as the Soviet Union, this will provide important new insight with respect to the projected performance of possible future in-country stations in the U.S.S.R. under a potential Comprehensive Test Ban Treaty.

The research under this contract has for the main part been concerned with the installation of a High Frequency Seismic Element (HFSE) in conjunction with the NORESS array. This represents a continuing effort, comprising acquisition and storage of data, regular data quality control and detailed analysis of events of particular interest. In addition the data are being made available to other research institutions. Furthermore, the research has comprised experimental installation of high-frequency filters in the NORSAR array and site studies, including experimental seismic array measurements, at selected sites in Fennoscandia.

In summary, the results obtained are as follows:

- Data from the HFSE have been received and stored on magnetic tape since late November 1985. A list of time intervals recorded during the contract period is provided in this report.

- During most of the contract period, the HFSE system has operated reliably, and provided high quality seismic data of exceptional dynamic range, resolution and bandwidth.

- From 10 March 1986, HFSE noise spectra have been computed automatically once per hour and stored on magnetic tape. Analysis of the temporal variations of these spectra has been undertaken.

- Signal and noise spectra have been computed for a number of seismic events. This has been used to study the propagation of high frequency energy contents of regional seismic phases as a function of epicentral distance.

The results from this research provide evidence that signal frequencies up to at least 50 Hz can contribute significantly to enhancing seismic monitoring capabilities at regional distances.

II. INTRODUCTION

NORSAR has, through the past several years, conducted extensive research on the propagation of seismic phases and the structure of the seismic noise field at high frequencies. The emphasis has been on studying high frequency signals recorded in Fennoscandia (Scandinavia and Finland) for seismic events from Eurasia. The associated travel paths have been shown in various studies to provide extremely efficient propagation of high frequency energy. Since Fennoscandia is located within the same geologic plate boundary as the Soviet Union, such studies will provide important new insight with respect to the projected performance of possible future in-country stations in the U.S.S.R. under a potential Comprehensive Nuclear Test Ban Treaty.

A major recent development has been the installation and on-going evaluation of a new experimental regional seismic array (NORESS) in Norway. Initial results from this system have been extremely encouraging, as the array has proved capable of taking advantage of the very efficient propagation of high-frequency seismic phases in Eurasia to provide a breakthrough in the detection and location of very small underground explosions at regional distances (0-2000 km).

The research under the present contract represents a follow-up to the NORESS results. The most important purpose is to expand the bandwidth of the seismic signals recorded in Norway, using the newly developed High Frequency Seismic Element (HFSE). In addition, some experimental deployments of high-frequency instrumentation have been undertaken, as discussed in the following.

III. FIELD INSTALLATIONS AND OPERATION

III.1 Description of the High Frequency Seismic Element (HFSE) system

The HFSE is an advanced seismic recording system, specially designed to record high frequency energy with high resolution and large dynamic range. The system, which is a self-contained, modular hardware package, has been designed and constructed by Sandia National Laboratories.

The HFSE utilizes the NORESS data link between the field site near Hamar and the NORSAR Data Center at Kjeller. This data link currently has an unused 19.2 Kbps channel and interfaces directly to the NORSAR computers. The HFSE is designed to be able to connect to this available data channel, but will in the future utilize a separate data link.

Being an experimental station, versatility of the design is an important attribute. The HFSE provides for both single axis and three axis field selectable implementations. The single axis (vertical) configuration has the widest bandwidth and permits studying frequencies to above 100 Hz. The three axis (Z,N,E) configuration permits the studying of vertical-horizontal relational characteristics of frequencies to above 50 Hz.

In the initial implementation, the three axis configuration has been chosen.

Digitizer

The digitizer is a Gould Inc. Enhanced Delta Modulation Encoder (EDME). The EDME provides 21 bits of dynamic range (120 dB) in a 24-bit format. The vertical axis EDME is configured as a dual sample rate device; both 125 and 250 Hz sampled data are provided to the system processor. The two horizontal EDMEs are configured as 125 Hz sample rate devices. The 250 Hz sample rate EDME incorporates a digital filter to obtain a usable bandwidth of 3-112 Hz. The 125 Hz sample rate EDME channels have a usable bandwidth of 3-56 Hz. The input voltage ranges are ±10 volts full scale for all channels.

Processor/Output:

A microprocessor handles the data bookkeeping and data buffering/blocking. A mode select switch selects the data input configuration: (Mode 1) Vertical - 250 Hz sample rate; (Mode 2) 3 axis - 125 Hz sampling rate.

Data are gathered into one-second blocks and sent to the IBM compatible SDLC protocol communications controller for output to a 19200 bps modem.

III.2 HFSE installation

The HFSE has been installed at the center site of the NORESS array. Data input is from a three-component short period seismometer of type Geotech S-3. The seismometer is emplaced in a 60 m borehole.

We note that the same seismometer is currently being used as one of the three-component sensors in the NORESS array (code F0). Thus, we have a possibility to verify the HFSE response in the frequency band where the two systems overlap (0-20 Hz). Figure III.1 shows the response of the HFSE and how it compares to that of NORESS instrumentation.

The HFSE installation was conducted during October/November 1985, in cooperation between Sandia and NORSAR personnel. Data have been available at the NORSAR Data Center since late November 1985, and are currently being stored permanently on magnetic tapes.

The seismometer used for HFSE is currently located at 60.735 N, 11.541 E, at an elevation of 247 m above sea level.

III.3 Recording intervals

The time intervals for which HFSE data have been recorded at NORSAR during the contract period are listed in Table III.1. This table also references the library number for magnetic tapes on which the data have been permanently stored.

HFSE data are available, on request, from NORSAR. The requestor will be provided with a detailed description of magnetic tape formats, data structure and system response curves. An agreement has been worked out with the Center for Seismic Studies (CSS) in Arlington, Virginia,

LIST OF DATA INTERVALS RECORDED BY THE HFSE
FOURTH QUARTER 1985

TAPE NO		START TIME	STOP TIME		
N- 18847	HF	318/10.42. 0.0	318/23.44.59.0	MODE	1
N- 18848	HF	318/23.45. 1.0	319/12.51.39.0	MODE	1
N- 18852	HF	319/12.51.40.0	320/ 1.52.48.0	MODE	1
N- 18853	HF	320/ 1.52.49.0	320/12.25.58.0	MODE	1
N- 18861	HF	320/12.26. 9.0	320/16.59.59.0	MODE	1
N- 18864	HF	324/13.25. 0.0	325/ 1. 7.19.0	MODE	1
N- 18871	HF	325/ 1. 7.20.0	325/12.56.49.0	MODE	1
N- 18878	HF	325/12.56.50.0	326/ 0.46.59.0	MODE	1
N- 18879	HF	326/ 0.47. 0.0	326/11.00.00.0	MODE	1
N- 18883	HF	326/13.00. 0.0	326/13.00.00.0	MODE	1
N- 18883	HF	326/13.45. 1.0	327/ 1.33.10.0	MODE	1
N- 18888	HF	327/ 1.33.11.0	327/13.20.20.0	MODE	1
N- 18889	HF	327/13.20.21.0	328/ 1. 7.30.0	MODE	1
N- 18890	HF	328/ 1. 7.31.0	328/12.54.40.0	MODE	1
N- 18891	HF	328/12.54.41.0	328/16.51.30.0	MODE	1
N- 18893	HF	328/16.51.31.0	329/ 4.39.50.0	MODE	1
N- 18895	HF	329/ 4.39.51.0	329/16.19.50.0	MODE	1
N- 18896	HF	329/16.19.51.0	330/ 4. 0.50.0	MODE	1
N- 18901	HF	330/ 4. 0.51.0	330/13.18.40.0	MODE	1
N- 18904	HF	330/13.18.41.0	331/ 0.59. 0.0	MODE	1
N- 18906	HF	331/ 0.59. 1.0	331/ 7.45.40.0	MODE	1
N- 18908	HF	331/10.51. 0.0	331/22.30.39.0	MODE	1
N- 18910	HF	331/22.30.40.0	332/10.10.39.0	MODE	1
N- 18915	HF	332/14.30. 0.0	333/ 2. 8.39.0	MODE	1
N- 18916	HF	333/ 2. 8.40.0	333/11.57.49.0	MODE	1
N- 18922	HF	333/11.57.50.0	333/23.37.39.0	MODE	1
N- 18923	HF	333/23.37.40.0	334/11.17.49.0	MODE	1
N- 18926	HF	334/11.17.50.0	334/22.57.49.0	MODE	1
N- 18927	HF	334/22.57.50.0	335/10.37.49.0	MODE	1
N- 18928	HF	335/10.37.50.0	337/ 5.51.49.0	MODE	1
N- 18933	HF	337/ 5.51.50.0	338/ 9.29.19.0	MODE	1
N- 18938	HF	338/ 9.29.20.0	340/ 4.38.59.0	MODE	1
N- 18939	HF	340/ 4.39. 0.0	340/ 4.39.29.0	MODE	1
N- 18951	HF	343/14.14. 0.0	345/ 8. 2. 9.0	MODE	1
N- 18965	HF	345/ 8. 2.10.0	347/ 3. 9. 9.0	MODE	1
N- 18969	HF	347/ 3. 9.10.0	347/ 8.40. 9.0	MODE	1
N- 18979	HF	348/ 9.45. 1.0	350/11.20. 9.0	MODE	1
N- 18982	HF	350/11.35. 0.0	352/ 6.50.29.0	MODE	1
N- 18987	HF	352/ 6.50.30.0	354/ 2.11.59.0	MODE	1
N- 18995	HF	354/ 2.12. 0.0	355/20.52.49.0	MODE	1
N- 19001	HF	355/20.52.50.0	357/15.27.39.0	MODE	1
N- 19006	HF	357/15.27.40.0	359/10.39.19.0	MODE	1
N- 19012	HF	359/10.39.20.0	361/ 5.50.19.0	MODE	1
N- 19019	HF	361/ 5.50.20.0	363/ 0.37.59.0	MODE	1
N- 19031	HF	364/ 7.10. 0.0	365/10. 0. 0.0	MODE	1
N- 19032	HF	364/10. 0. 1.0	365/23.59.59.0	MODE	1

Table III.1 (4 parts)
List of data intervals recorded by the HFSE system.
Part 1: 4th Quarter 1985

TAPE NO.		CREAT. DATE	DATA DATE	START TIME	STOP TIME	
19036	HFTAPE	1/ 1/86	1/ 1/86	0000010	1913200	HF-REC
19044	HFTAPE	1/ 3/86	1/ 2/86	1913210	0316300	HF-REC
19052	HFTAPE	1/ 5/86	1/ 5/86	0930000	0506490	HF-REC
19056	HFTAPE	1/ 7/86	1/ 7/86	0506500	0018290	HF-REC
19063	HFTAPE	1/ 9/86	1/ 9/86	0018300	1930490	HF-REC
19070	HFTAPE	1/11/86	1/10/86	1930500	1443190	HF-REC
19075	HFTAPE	1/14/86	1/13/86	1443200	0956390	HF-REC
19087	HFTAPE	1/25/86	1/24/86	1335200	0851290	HF-REC
19091	HFTAPE	1/14/86	1/14/86	0956400	0508390	HF-REC
19096	HFTAPE	1/16/86	1/16/86	0508400	0723590	HF-REC
19100	HFTAPE	1/17/86	1/17/86	0724000	0254490	HF-REC
19105	HFTAPE	1/19/86	1/19/86	0254500	2228390	HF-REC
19112	HFTAPE	1/21/86	1/20/86	2228400	1759390	HF-REC
19120	HFTAPE	1/23/86	1/22/86	1759400	1335190	HF-REC
19131	HFTAPE	1/26/86	1/26/86	0851300	0933090	HF-REC
19142	HFTAPE	1/31/86	1/30/86	0933100	0510490	HF-REC
19147	HFTAPE	2/ 1/86	2/ 1/86	0510500	1656590	HF-REC
19152	HFTAPE	2/ 3/86	2/ 2/86	1657000	1231590	HF-REC
19160	HFTAPE	2/ 5/86	2/ 4/86	1232000	0448090	HF-REC
19176	HFTAPE	2/ 7/86	2/ 7/86	0448100	2351190	HF-REC
19184	HFTAPE	2/ 9/86	2/ 8/86	2351200	1939490	HF-REC
19193	HFTAPE	02/12/86	02/11/86	1939500	1451590	HF-REC
19200	HFTAPE	02/14/86	02/13/86	1452000	1005290	HF-REC
19206	HFTAPE	02/16/86	02/15/86	1005300	0518090	HF-REC
19229	HFTAPE	02/17/86	02/17/86	0518100	0007190	HF-REC
19239	HFTAPE	02/19/86	02/19/86	0007200	1919290	HF-REC
19243	HFTAPE	02/21/86	02/20/86	1919300	1436390	HF-REC
19248	HFTAPE	02/23/86	02/22/86	1436400	0950590	HF-REC
19257	HFTAPE	02/25/86	02/24/86	0951000	0500190	HF-REC
19260	HFTAPE	02/26/86	02/26/86	0500200	0012190	HF-REC
19273	HFTAPE	03/02/86	03/01/86	1923200	1431190	HF-REC
19280	HFTAPE	03/04/86	03/03/86	1431200	0935290	HF-REC
19290	HFTAPE	03/06/86	03/05/86	0935300	0449390	HF-REC
19305	HFTAPE	03/07/86	03/07/86	0449400	2347090	HF-REC
19310	HFTAPE	03/09/86	03/08/86	2347100	1851390	HF-REC
19318	HFTAPE	03/11/86	03/10/86	1851400	1408290	HF-REC
19325	HFTAPE	03/13/86	03/12/86	1408300	1958190	HF-REC
19331	HFTAPE	03/15/86	03/14/86	1958200	2000000	HF-REC
19337	HFTAPE	03/18/86	03/17/86	1034000	1755590	HF-REC
19346	HFTAPE	03/23/86	03/22/86	1303000	2309590	HF-REC
19360	HFTAPE	03/25/86	03/24/86	2310000	0720490	HF-REC
19369	HFTAPE	03/26/86	03/26/86	0720490	1818390	HF-REC
19382	HFTAPE	03/31/86	03/30/86	2350000	1904390	HF-REC

Table III.1 Part 2: 1st Quarter 1986

N- 19382	HF	89/23.50. 0.0- 91/19. 4.39.0	MODE 1
N- 19385	HF	91/19. 4.40.0- 93/14.25.59.0	MODE 1
N- 19390	HF	93/14.26. 0.0- 95/ 9.41.29.0	MODE 1
N- 19395	HF	95/ 9.41.30.0- 97/ 4.57.29.0	MODE 1
N- 19402	HF	97/ 4.57.30.0- 99/ 0.12. 9.0	MODE 1
N- 19407	HF	99/ 0.12.10.0-100/19.33.49.0	MODE 1
N- 19413	HF	100/19.33.50.0-101/ 6.14.29.0	MODE 1
N- 19419	HF	101/ 6.14.30.0-102/ 8.50.39.0	MODE 1
N- 19422	HF	102/ 8.50.40.0-104/ 3.39.39.0	MODE 1
N- 19427	HF	104/ 3.39.40.0-105/22.55.39.0	MODE 1
N- 19432	HF	105/22.55.40.0-107/18.10.59.0	MODE 1
N- 19443	HF	107/18.11. 0.0-109/13.55.29.0	MODE 1
N- 19449	HF	109/13.55.30.0-111/ 8.40.39.0	MODE 1
N- 19456	HF	111/ 8.40.40.0-113/18.33.59.0	MODE 1
N- 19461	HF	113/18.34. 0.0-115/14.19. 9.0	MODE 1
N- 19467	HF	115/14.19.10.0-119/23.13.29.0	MODE 1
N- 19476	HF	119/23.13.30.0-121/18.42.59.0	MODE 1
N- 19485	HF	121/18.43. 0.0-123/14. 7.29.0	MODE 1
N- 19494	HF	123/14. 7.30.0-125/ 8.28.19.0	MODE 1
N- 19497	HF	125/ 8.28.20.0-127/21.54.49.0	MODE 1
N- 19505	HF	127/21.54.50.0-129/17.26.39.0	MODE 1
N- 19512	HF	129/17.26.40.0-131/13. 6.29.0	MODE 1
N- 19518	HF	131/13. 6.30.0-133/ 8.51. 9.0	MODE 1
N- 19524	HF	133/ 8.51.10.0-135/ 4.27. 9.0	MODE 1
N- 19531	HF	135/ 8.29. 0.0-137/ 4. 9.29.0	MODE 1
N- 19537	HF	137/ 4. 9.30.0-138/23.51.19.0	MODE 1
N- 19543	HF	138/23.51.20.0-140/19.28.39.0	MODE 1
N- 19549	HF	140/19.28.40.0-142/ 2.10.39.0	MODE 1
N- 19556	HF	142/ 2.10.40.0-143/23.29.49.0	MODE 1
N- 19563	HF	143/23.29.49.0-143/23.29.48.0	MODE 1
N- 19563	HF	146/ 5.52. 0.0-148/ 1.37. 9.0	MODE 1
N- 19572	HF	148/ 1.37.10.0-149/21.20.49.0	MODE 1
N- 19581	HF	149/21.20.50.0-151/16.59.39.0	MODE 1
N- 19585	HF	151/16.59.40.0-153/12.31.29.0	MODE 1
N- 19593	HF	153/12.31.30.0-155/ 8.18. 9.0	MODE 1
N- 19598	HF	155/ 8.18.10.0-157/ 3.59.59.0	MODE 1
N- 19602	HF	157/ 4. 0. 0.0-158/23.40.29.0	MODE 1
N- 19609	HF	158/23.40.30.0-160/19.19.49.0	MODE 1
N- 19616	HF	160/19.19.50.0-163/ 5.14.29.0	MODE 1
N- 19622	HF	163/ 5.14.30.0-165/ 0.54.19.0	MODE 1
N- 19629	HF	165/ 0.54.20.0-165/16.34. 9.0	MODE 1
N- 19633	HF	165/16.34.10.0-167/12.15.39.0	MODE 1
N- 19637	HF	167/12.15.40.0-169/ 6.38.39.0	MODE 1
N- 19647	HF	169/ 6.38.40.0-170/23.15.48.0	MODE 1
N- 19653	HF	170/23.15.49.0-172/19. 2.28.0	MODE 1
N- 19661	HF	172/19. 2.29.0-174/14.48.58.0	MODE 1
N- 19669	HF	174/14.48.59.0-174/ 8.32.28.0	MODE 1
N- 19674	HF	176/ 9.32.28.0-178/ 5.18. 7.0	MODE 1
N- 19678	HF	178/ 5.18. 8.0-180/ 1. 4.37.0	MODE 1
N- 19685	HF	180/ 1. 4.38.0-181/20.50.37.0	MODE 1
N- 19693	HF	181/20.50.38.0-183/16.24.17.0	MODE 1

Table III.1 Part 3: 2nd Quarter 1986

N-	19714	HF	183/16.24.18.0-185/10. 2.36.0	MODE	1
N-	19720	HF	185/10. 2.37.0-187/ 5.47. 6.0	MODE	1
N-	19724	HF	187/ 5.47. 7.0-189/ 1.14. 6.0	MODE	1
N-	19731	HF	189/ 1.14. 7.0-191/18.20.59.0	MODE	1
N-	19739	HF	191/18.21. 0.0-193/13.59.39.0	MODE	1
N-	19745	HF	193/13.59.40.0-195/ 9.39.49.0	MODE	1
N-	19753	HF	195/ 9.39.50.0-197/ 5.27.19.0	MODE	1
N-	19757	HF	197/ 5.27.20.0-199/ 1. 6.19.0	MODE	1
N-	19762	HF	199/ 1. 6.20.0-200/20.47. 9.0	MODE	1
N-	19769	HF	200/20.47.10.0-202/16.27.49.0	MODE	1
N-	19778	HF	202/16.27.50.0-202/10. 8. 9.0	MODE	1
N-	19785	HF	202/10. 8.10.0-204/ 5.38.19.0	MODE	1
N-	19786	HF	204/ 5.38.20.0-206/ 1.11.39.0	MODE	1
N-	19790	HF	206/ 1.11.40.0-207/20.17.29.0	MODE	1
N-	19797	HF	207/20.17.30.0-209/15.38. 9.0	MODE	1
N-	19803	HF	209/15.38.10.0-211/23.30.14.0	MODE	1
N-	19811	HF	211/23.30.15.0-212/21.29.34.0	MODE	1
N-	19817	HF	212/21.29.35.0-213/ 6. 0. 4.0	MODE	1
N-	19819	HF	213/16. 8. 0.0-215/11.26.19.0	MODE	1
N-	19829	HF	215/11.26.20.0-217/ 7. 8.39.0	MODE	1
N-	19838	HF	217/ 7. 8.40.0-219/ 2.47.29.0	MODE	1
N-	19846	HF	219/ 2.47.30.0-220/22.16.29.0	MODE	1
N-	19848	HF	220/22.16.30.0-222/17.19.29.0	MODE	1
N-	19861	HF	222/17.19.30.0-222/10.52.59.0	MODE	1
N-	19865	HF	222/10.53. 0.0-223/12.53. 9.0	MODE	1
N-	19866	HF	223/12.53.10.0-224/14.53. 9.0	MODE	1
N-	19867	HF	224/14.53.10.0-225/16.53.19.0	MODE	1
N-	19875	HF	225/16.53.20.0-224/16.53.29.0	MODE	1
N-	19877	HF	224/16.53.30.0-225/18.53.39.0	MODE	1
N-	19879	HF	225/18.53.40.0-226/17.55. 9.0	MODE	1
N-	19880	HF	227/ 5.40. 0.0-226/ 5.40. 9.0	MODE	1
N-	19881	HF	228/ 9.26. 0.0-229/11.26. 9.0	MODE	1
N-	19891	HF	229/11.26.10.0-231/10.41.29.0	MODE	1
N-	19891	HF	229/11.26.10.0-231/ 7.13.49.0	MODE	1
N-	19894	HF	231/ 7.13.50.0-233/ 2.51. 9.0	MODE	1
N-	19901	HF	233/ 2.51.10.0-234/22.29. 9.0	MODE	1
N-	19907	HF	234/22.29.10.0-234/22.29.19.0	MODE	1
N-	19907	HF	234/22.29.20.0-236/13. 5.49.0	MODE	1
N-	19912	HF	236/13. 5.50.0-238/ 8.43.29.0	MODE	1
N-	19918	HF	238/ 8.43.30.0-239/10.26. 9.0	MODE	1
N-	19922	HF	239/10.26.10.0-240/ 7.28.19.0	MODE	1
N-	19926	HF	240/ 7.28.20.0-241/ 9.28.29.0	MODE	1
N-	19939	HF	242/12.49. 0.0-243/14.49. 9.0	MODE	1
N-	19944	HF	243/14.49.10.0-244/16.49.19.0	MODE	1
N-	19952	HF	246/12.40. 0.0-247/14.40. 9.0	MODE	1
N-	19956	HF	247/14.40.10.0-248/16.40.19.0	MODE	1
N-	19959	HF	248/16.40.20.0-249/18.40.29.0	MODE	1
N-	19964	HF	249/18.40.30.0-250/20.40.39.0	MODE	1
N-	19969	HF	250/20.40.40.0-251/22.40.49.0	MODE	1
N-	19973	HF	251/22.40.50.0-253/ 0.40.59.0	MODE	1
N-	19976	HF	253/ 0.41. 0.0-254/ 2.41. 9.0	MODE	1
N-	19995	HF	256/13. 0. 1.0-257/15. 0.10.0	MODE	1
N-	20000	HF	257/15. 0.11.0-258/17. 0.10.0	MODE	1
N-	20001	HF	258/17. 0.11.0-259/19. 0.20.0	MODE	1
N-	20006	HF	259/19. 0.21.0-260/21. 0.30.0	MODE	1
N-	20009	HF	260/21. 0.31.0-261/ 7.24.40.0	MODE	1
N-	20013	HF	261/ 7.24.41.0-262/ 9.24.40.0	MODE	1
N-	20015	HF	262/ 9.24.41.0-263/ 8.58.40.0	MODE	1
N-	20018	HF	263/ 8.58.41.0-264/10.58.50.0	MODE	1

Table III.1 Part 4: 3rd Quarter 1986

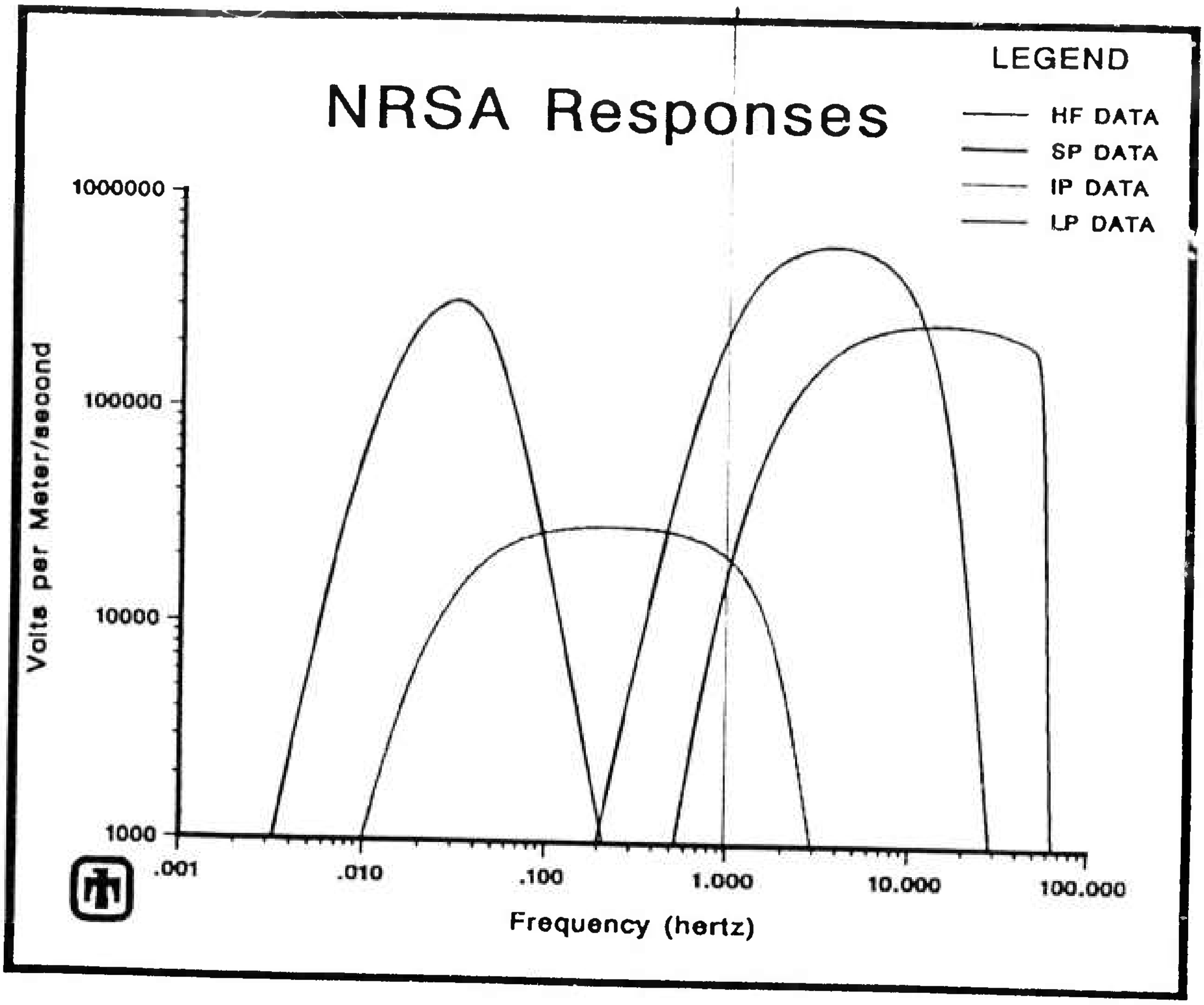


Fig. III.1 Response characteristics of different instrumentation in use at NORESS. The figure has been provided by Sandia National Laboratories.

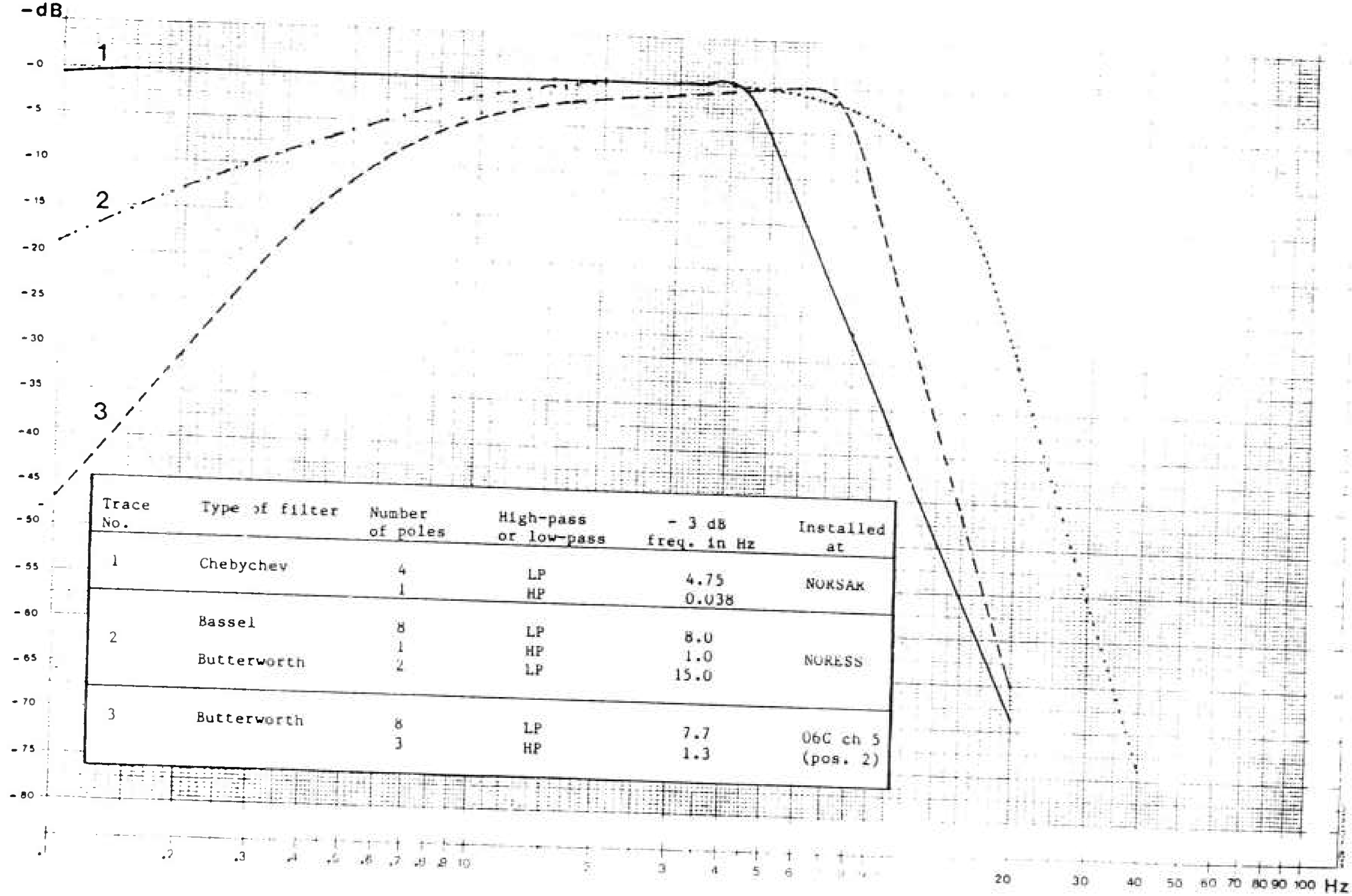
under which the CSS will receive all recorded HFSE data and undertake to redistribute requested data to US contractors.

III.4 Other high frequency instrumentation

A new analog filter with an upper cutoff frequency of 8 Hz has been experimentally installed at the NORSAR array (seismometer 06C05). The filter attenuation characteristics are shown in Figure III.2 together with corresponding graphs for the "standard" NORSAR SP and the NORESS SP filters.

The new filter implies that the recorded SP signal matches closely the one recorded using NORESS SP instrumentation, as can bee seen from Figure III.3, where four different co-located SP systems in operation at NORSAR are shown on the same plot for a local seismic event. Note in particular how the low frequency Rg phase is dominant on the "standard" NORSAR instrument 06C02, whereas it is virtually absent on the High Frequency Element. On the other hand, the P and S phases are much more prominent on the high frequency systems.

We have also conducted some site surveys for possible additional high frequency array installations. Example of recordings from one such site are shown in Fig. III.4. Our investigations so far indicate that there is a degree of similarity at various sites in Fennoscandia with regard to the high frequency seismic noise field. This comprises both the general noise level at frequencies above 2 Hz and also noise correlation between sensors as a function of distance. We have thus found no compelling reason for selecting an array geometry different from that of NORESS for a future array installation.



Trace No.	Type of filter	Number of poles	High-pass or low-pass	- 3 dB freq. in Hz	Installed at
1	Chebychev	4 1	LP HP	4.75 0.038	NORSAR
2	Bassel Butterworth	8 1 2	LP HP LP	8.0 1.0 15.0	NORESS
3	Butterworth	8 3	LP HP	7.7 1.3	06C ch 5 (pos. 2)

Fig. III.2 Comparison of analog filter attenuation characteristics for (1) Standard NORSAR SP; (2) NORESS SP; (3) Modified NORSAR SP.

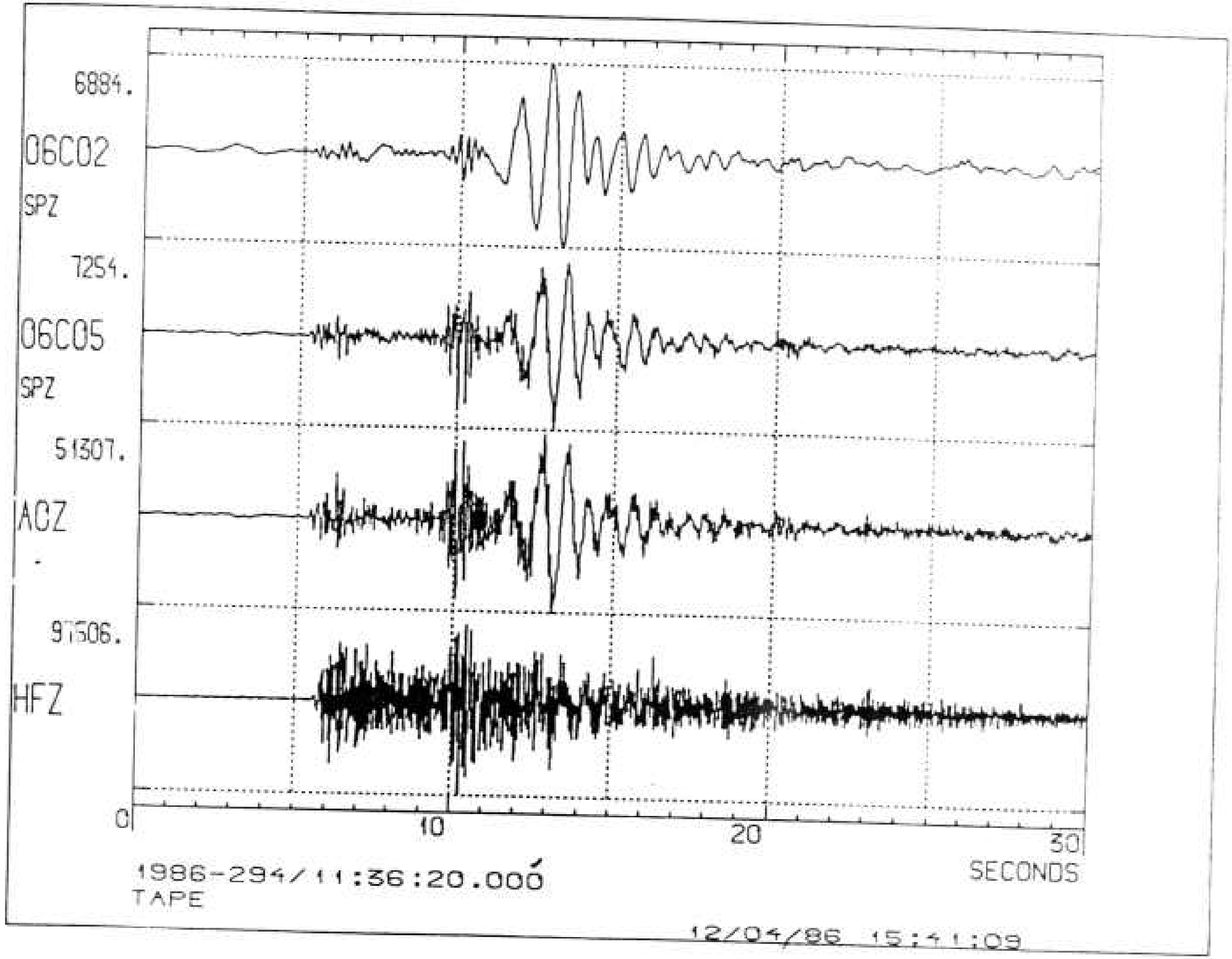


Fig. III.3 Examples of recordings by different SP systems in use at NORSAR, for local event. All four instruments shown are co-located at the NORESS center. From top to bottom they are:
06C02: NORSAR standard SP instrumentation; 06C05: NORSAR modified SPZ (8 Hz filter);
AOZ: NORESS center SPZ seismometer; HFZ: High Frequency Element (vert. comp.)

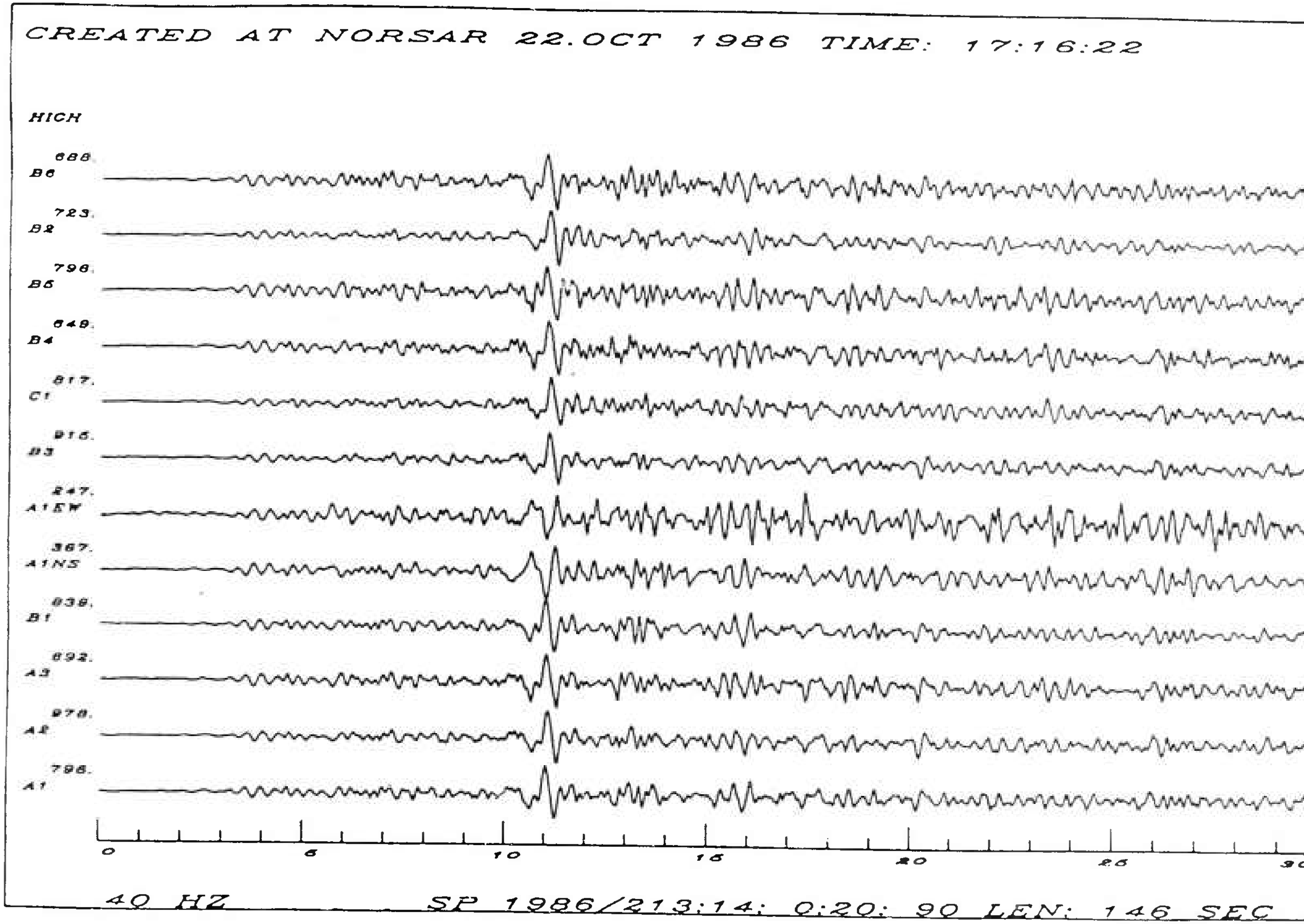


Fig. III.4 Example of a P-phase for a regional event (Δ = 1200 km) recorded at an experimental small-aperture array (diameter 1 km) at a distance of about 800 km from NORESS. Note the strong mantle phase at about the 10 second mark.

IV. EQUIPMENT PURCHASED

The following equipment has been purchased under this contract:

Line Multiplexer (2 ea, type MEGAMUX)
Central Recording Unit.

The two line multiplexers have been installed at the NORESS field site and at Kjeller, respectively, and provide for multiplexing the 19.2 Kbps HFSE data stream on to the NORESS 64 Kbps land line to Kjeller.

V. DATA ANALYSIS

In earlier quarterly technical reports under this contract, results of analysis of the high frequency data have been described in detail. In this final report, we summarize some of the most important findings.

We have conducted a systematic study of the spectral characteristics of HFSE-recorded seismic phases, and in total processed more than 100 events at local and regional distances.

Noise spectra have been estimated using the indirect covariance method. We first estimate the correlation function by splitting a long data record into many windows, calculating a sample correlation function for each window, then averaging the sample correlation functions. Typically, we use 20 windows, each of which is 5 seconds long. Because the earth noise has such a large dynamic range, we prewhiten it prior to estimating the correlation function with a low-order prediction-error filter. The spectrum is then estimated by windowing the correlation function with a 3-second Hamming window, then computing the Fourier transform. The spectral estimate obtained this way is compensated then for the effects of prewhitening and normalized to a 1-second window length.

Signal spectra have been estimated using the same technique, but with 4 overlapping windows, each of 7 seconds length. Start times of these windows are 3, 2, 1 and 0 seconds before signal onset, respectively. Thus we achieve a smoothing of the signal spectra while retaining compatibility with the noise spectra.

Fig. V.1 shows, schematically, a suite of smoothed P-wave spectra representing typical regional events, at various distances, recorded at the HFSE. The figure has been compiled on the basis of about 100 regional events, and represents average spectra over all azimuths, scaled to magnitude $M_L = 3.0$.

The figure illustrates the strong distance-dependence of high frequency signal energy. Of particular interest is the observation that the signal and noise spectra are approximately in parallel across the entire frequency band for distances out to about 500 km. Thus, within this distance range, the possibility of utilizing high frequencies for event characterization are excellent even at very low magnitudes. At further distances, the signal spectra start to merge with the noise (the crossover point being dependent on distance as well as magnitude). E.g., at 900-1000 km there seems to be significant SNR at $M_L = 3$ for frequencies up to about 25 Hz.

It must be noted that we have observed considerable spectral variability with source type and location, even within limited distance ranges. Thus Fig. V.1 must be interpreted accordingly.

Seismic noise characteristics

Seismic noise at high frequencies (2 Hz and up to 50 Hz) show strong correlation with cultural activity, and are at their highest level during workdays. The amount of diurnal variation (measured in dB) remains about constant in this band, the only exception being a few

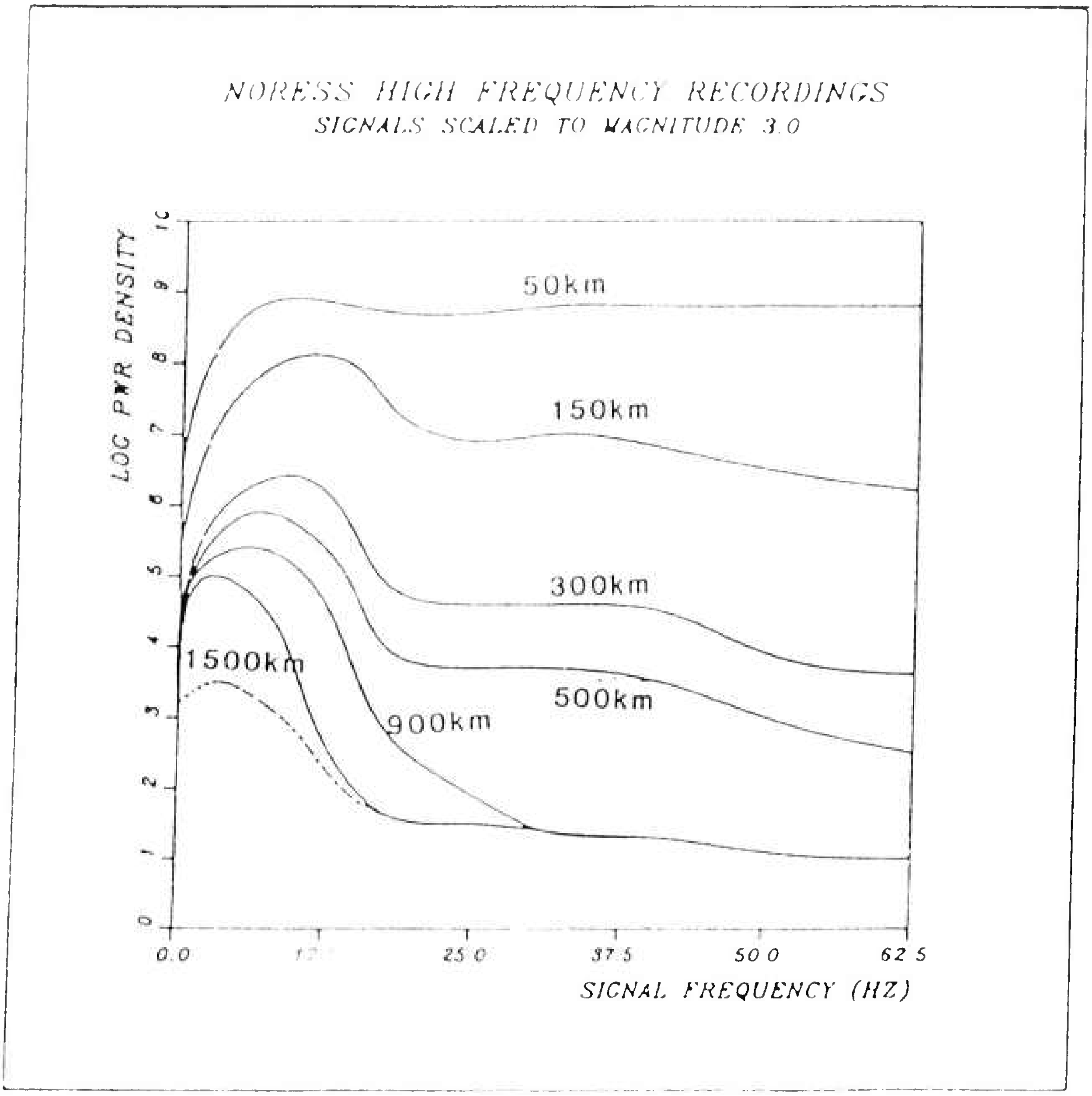


Fig. V.1 Schematic illustration of high frequency P-wave spectra recorded at the HFSE, at various regional distances. The figures represents average features of about 100 regional events at various distances and azimuths, all scaled to M_L = 3.0. A typical noise spectrum is shown as a dotted line. Note that a considerable smoothing has been applied to the spectra, and that there are significant variations between individual events, even within limited epicentral distances.

narrow noise peaks related to particularly strong single noise sources.

Figure V.2 shows, as an example, hourly noise spectra for a typical day (Friday, 14 March 1986) based on the vertical HFSE component. A total of 24 noise spectra are plotted to the same scale. The spectra have not been corrected for system response.

A noteworthy feature is distinct noise peaks at selected frequencies. The strong peaks around 30 and 40 Hz apparently reflect noise interferences caused by mechanical equipment installed in the NORESS hub (fans, etc.), and is not thought to represent any malfunctioning of the HFSE, nor actual earth noise. The peaks seen at 6 and 12 Hz are typical of daytime hours, and seem to be generated by a sawmill located about 15 km from the site.

The ensemble of noise spectra is generally quite concentrated at all frequencies, except for one or two "outliers" which may represent disturbance caused by small local seismic events. Although not indicated on the plots, the spectra computed during local daytime typically lie above the nighttime spectra.

Figure V.3 shows Z-component HF spectra (corrected) together with other NORSAR/NORESS spectra for a typical nighttime noise sample. The data are consistent with previously published "low noise" models.

It is important to note in this regard that many model studies earlier conducted on projected seismic monitoring capabilities have been based on estimates of seismic noise levels that have been measured during "quiet" conditions. Even though a standard deviation is associated with these levels, it is clear that a much more reliable assessment can be obtained if actual noise measurements over extended time periods are available.

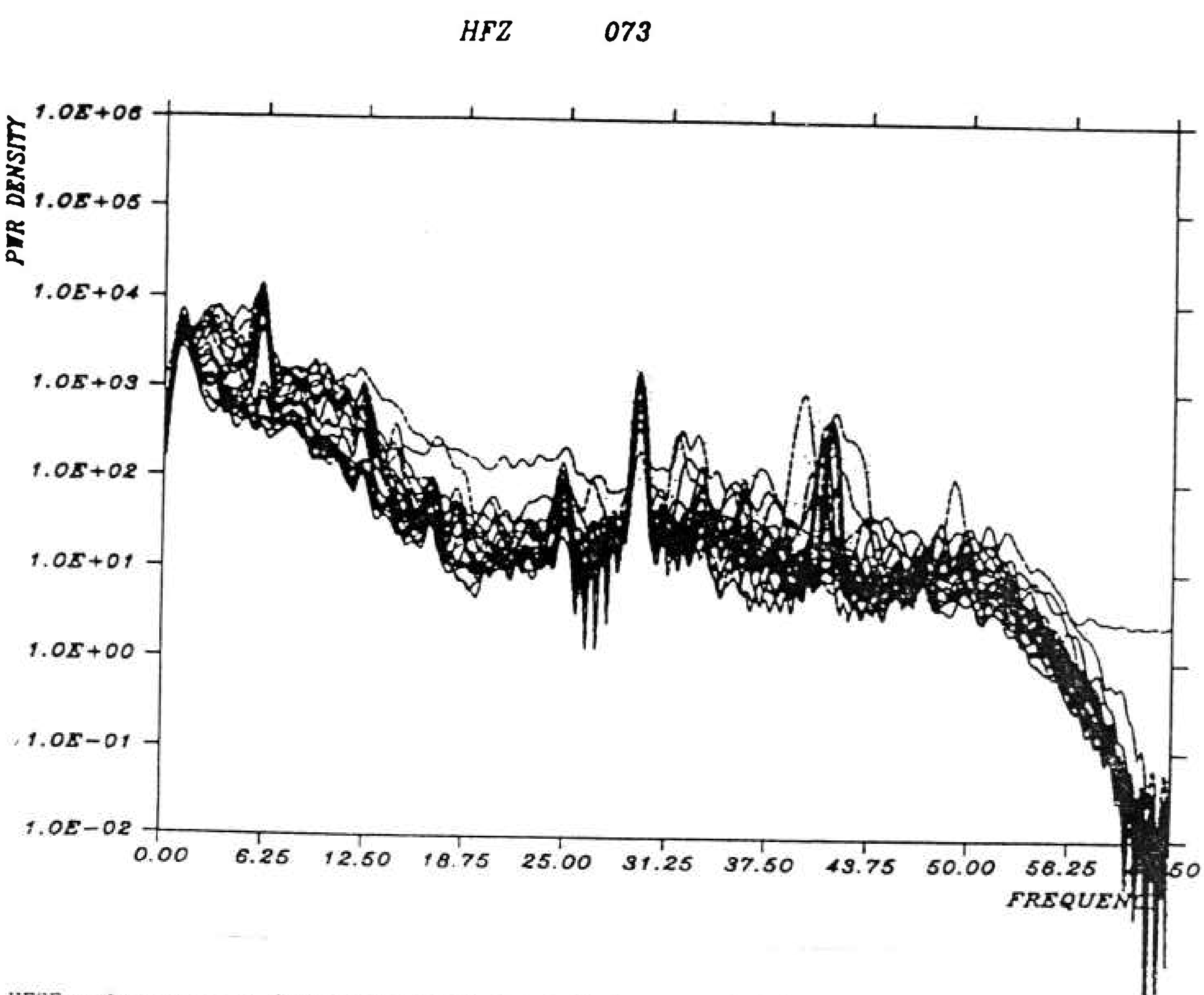


Fig. V.2 HFSE noise spectra (SPZ component) for a 24-hour period (Friday, 14 March 1986). A total of 24 spectra, sampled at one-hour intervals, are shown. The spectra have not been corrected for system response. The interval between tick marks on the vertical axis corresponds to 10 dB. Reference is made to the text for interpretation of some of the basic features shown.

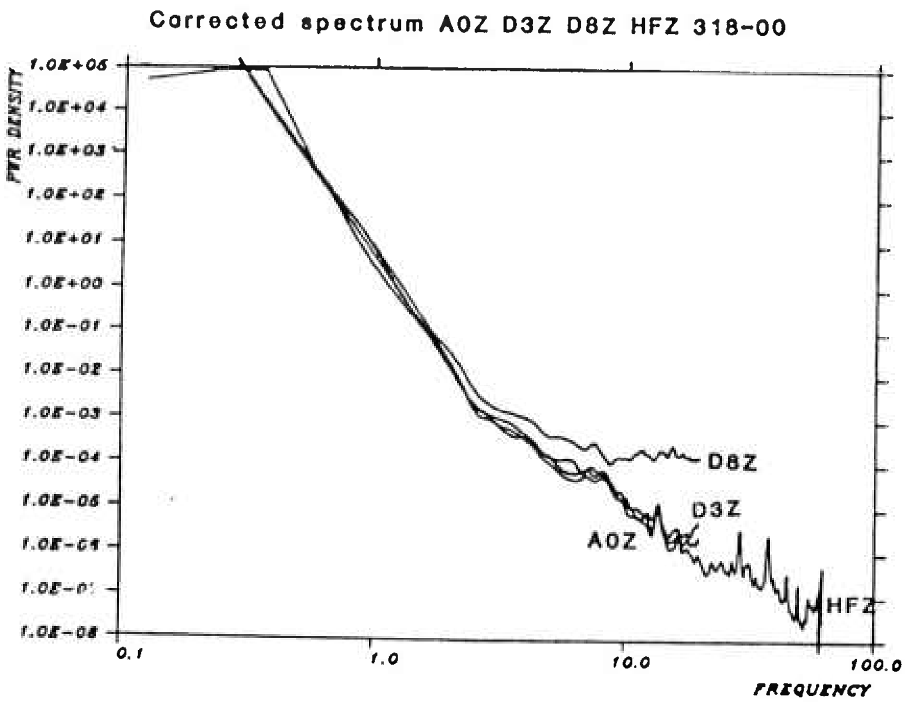


Fig. V.3 Corrected noise spectra for A0Z, D3Z, D8Z, HFZ observed day 318 at 00 GMT. The power density unit is nm^2/Hz.

Event analysis

An example of the important additional information provided by the high frequency recordings is given in Fig. V.4. This figure corresponds to an M_L = 5.0 earthquake off the west coast of Norway on February 5, 1986 (distance = 417 km). The unfiltered record shows the expected amplitude pattern, i.e., Lg as the dominant phase, Pg much larger than Pn. The picture changes dramatically when considering the high-frequency part of the record. In the filter band 30-50 Hz, the Pn and Sn phases dominate the seismogram, and the Pg and Lg phases are not even visible.

Fig. V.5 shows HFSE spectra from the vertical component for the same event. We see that Lg exceeds the preceding noise (which in fact is the Sn coda) only up to about 10 Hz, whereas Pn has large SNR over the entire frequency band.

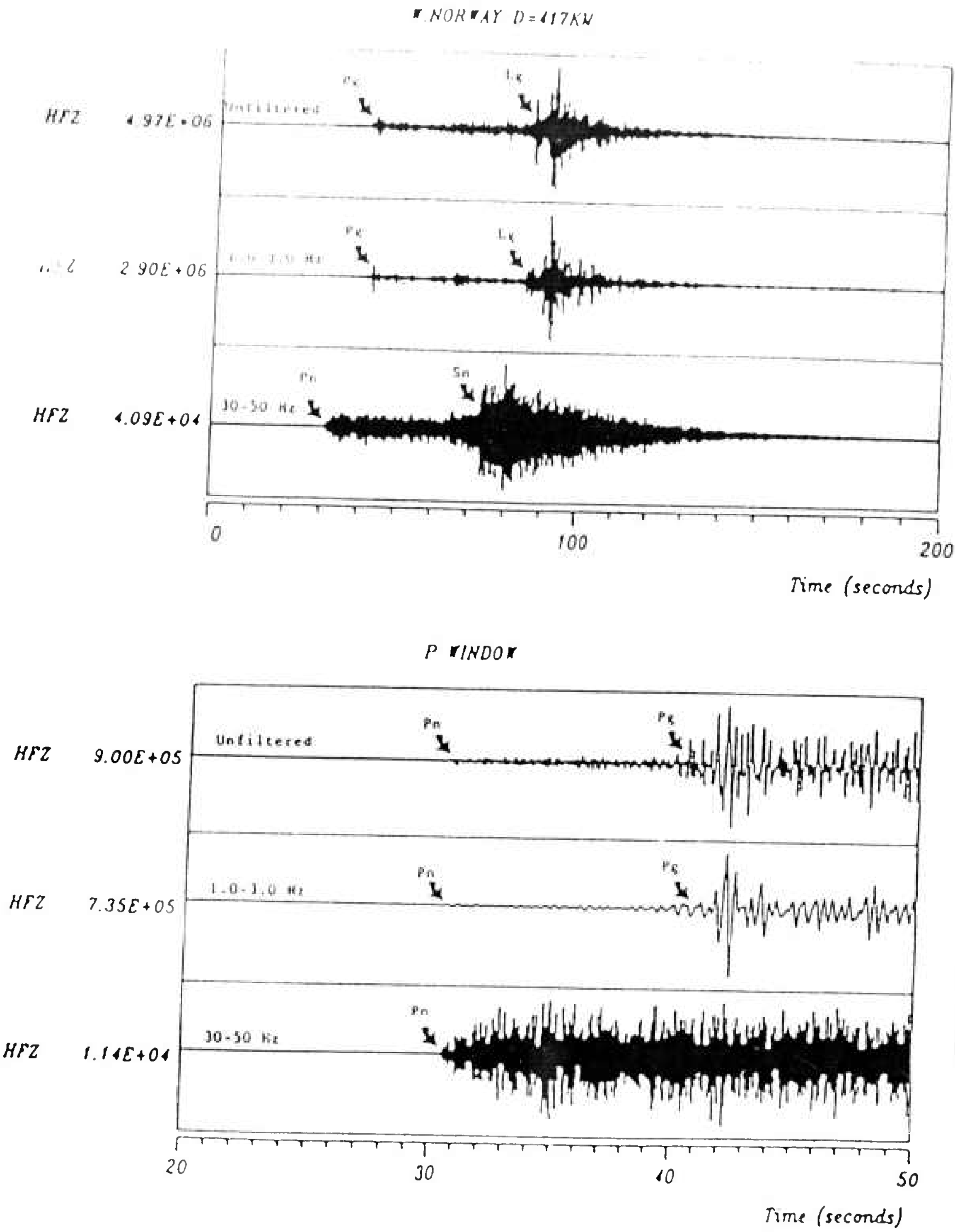


Fig. V.4 Time domain plots of the HFSE recordings of the SPZ channel at NORESS for an M_L = 5.0 earthquake off the west coast of Norway (distance = 417 km). The upper part covers the entire wavetrain (unfiltered and in two filter bands as indicated). The bottom part is an expanded view of the P window. Note the prominence of Pn and Sn in the high-frequency band.

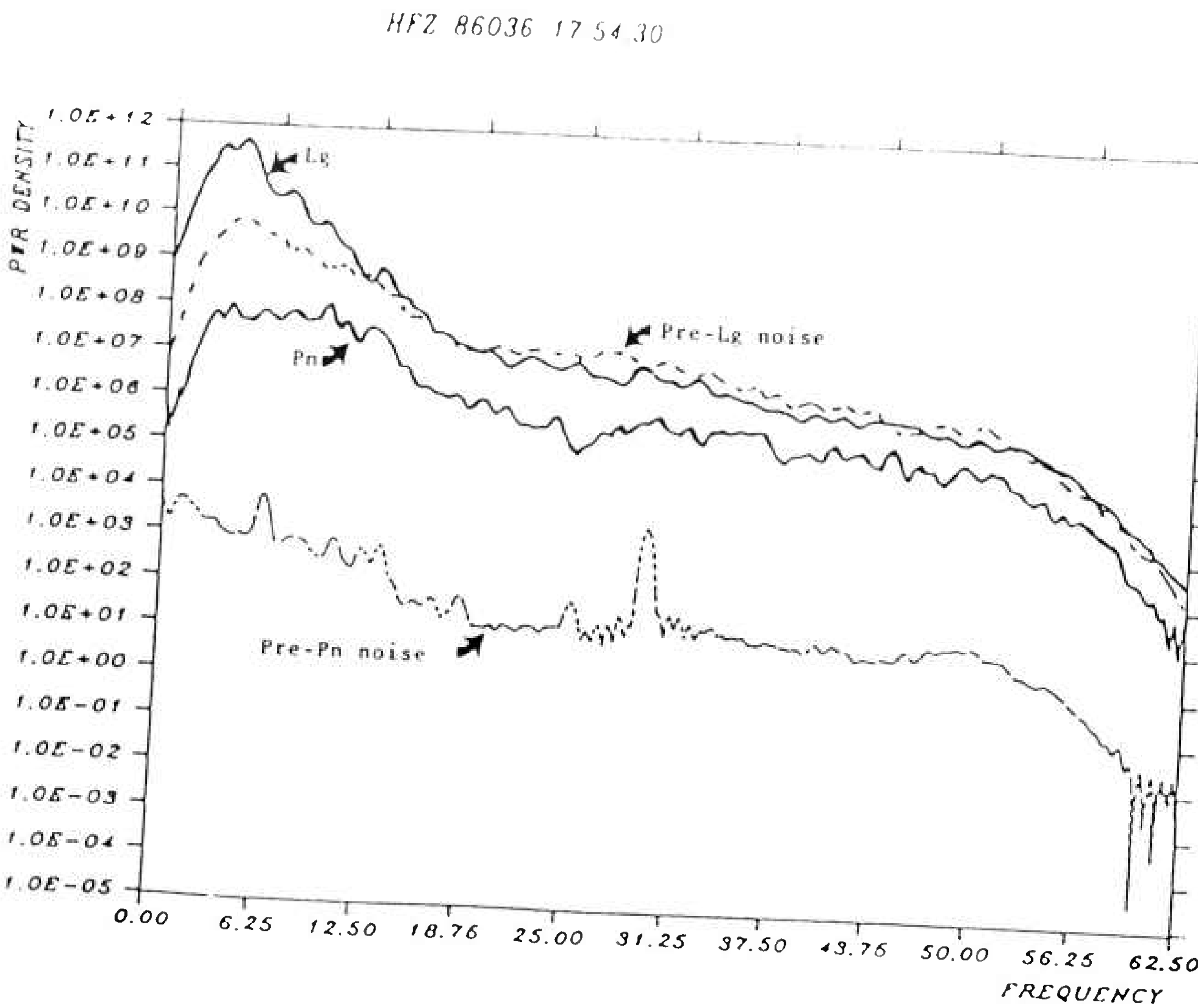


Fig. V.5 Spectral plot of the Pn and Lg phases for the event shown in Fig. V.4. Note that the Pn SNR remains approximately constant across the entire high-frequency part of the spectrum.